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Dust Control on Longwall Shearers Using Water-Jet-Assisted Cutting

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

ft	foot	in	inch
ft/min	foot per minute	mg/m^3	milligram per cubic meter
ft^2	square foot	mm	millimeter
ft^3/min	cubic foot per minute	pct	percent
gal/min	gallon per minute	psi	pound per square inch
hp	horsepower	r/min	revolution per minute

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DUST CONTROL ON LONGWALL SHEARERS USING WATER-JET-ASSISTED CUTTING

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ABSTRACT

The Bureau of Mines equipped a longwall shearer with a water-jet-assisted cutting system and measured dust levels during the cutting of a simulated coal block. The block was cut dry, at a conventional water spray pressure of 190 psi, and with water-jet-assisted cutting pressures ranging from 1,000 to 6,000 psi. At water pressures of 3,000 psi and higher, dust concentrations were reduced by as much as 85 pct via water-jet-assisted cutting in comparison with conventional water sprays. This reduction was achieved without any increase in the water flow rate.

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INTRODUCTION

Large quantities of respirable dust are generated by the cutting action of a longwall shearer. All longwall sections use sprayed water as a dust control technique. Generally, spray nozzles are mounted on the body of the shearer and directed toward the cutting drum. These sprays remove part of the airborne dust by impacting the dust particles with water droplets. The efficiency of airborne dust removal by impaction is improved by increasing the quantity and pressure of the water supplied. The most effective use of water for dust control results from adding moisture to the generated dust particles before they become airborne. This requires wetting the dust as close as practical to its point of origin. For a longwall shearer, this is the point where the bit strikes the coal.

All U.S. longwall shearers are equipped with a water spray system that directs water through the cutting drum. The water passes from the drum to spray nozzles, usually located in front of each bit, which direct water to the bit tip. For these conventional spray systems, the water pressure at the nozzle is typically 100 to 200 psi.

Techniques for using high-pressure water jets to assist the cutting of rock have been evaluated by the Bureau of Mines and others (1).[4] For this report a water jet is defined as a high-pressure solid stream of water that is directed to a point within 5 mm of the bit tip. The coherent stream, achieved by using a specially designed spray nozzle, is necessary for maximum transfer of energy between the nozzle orifice and rock surface. Use of high-pressure water jets to assist a mechanical drag bit is known as water-jet-assisted cutting. Laboratory test results have shown that when cutting at shallow depths, forces on a drag bit are reduced if a high-pressure water jet is directed toward the bit tip (2). To date no underground studies have documented these force reductions, but use of roadheaders equipped with water jets has demonstrated improved cutting efficiency (3).

In addition to improved cutting efficiency with water-jet-assisted cutting, the quantity of dust generated was noted as also being reduced. A dust sampling plan was designed to determine the relationship between water usage and the quantity of dust generated by the cutting action of a longwall shearer drum equipped for water-jet-assisted cutting. This report describes testing performed to evaluate the effectiveness of high-pressure versus conventional-pressure water sprays for dust control on a longwall shearer.

TEST FACILITY

Testing to determine the effects of water usage on dust levels was conducted using a 60-ft-long by 6-ft-high coalcrete block, composed of coal, fly ash, and concrete, to simulate a longwall face. Because of its higher silica content, coalcrete is more abrasive than coal; however, when using conventional drag bits, its cutting properties are similar. Overall the simulated coal face was homogeneous. A longwall panline, adjacent to the coalcrete block, provided continuous removal of the coalcrete as it was cut.

The shearer used to cut the coalcrete was a Joy 1-LS1[5] double-drum machine (fig. 1). For all tests, only the lead drum was used for cutting; the trailing drum was positioned so that it moved within the cut made by the lead drum. The lead drum diameter (bit tip to bit tip) was 54 in, and the drum width was 28 in. During the tests, web width

[4]Underlined numbers in parentheses refer to items in the list of references at the end of this report.

[5]Reference to specific products does not imply endorsement by the Bureau of Mines.

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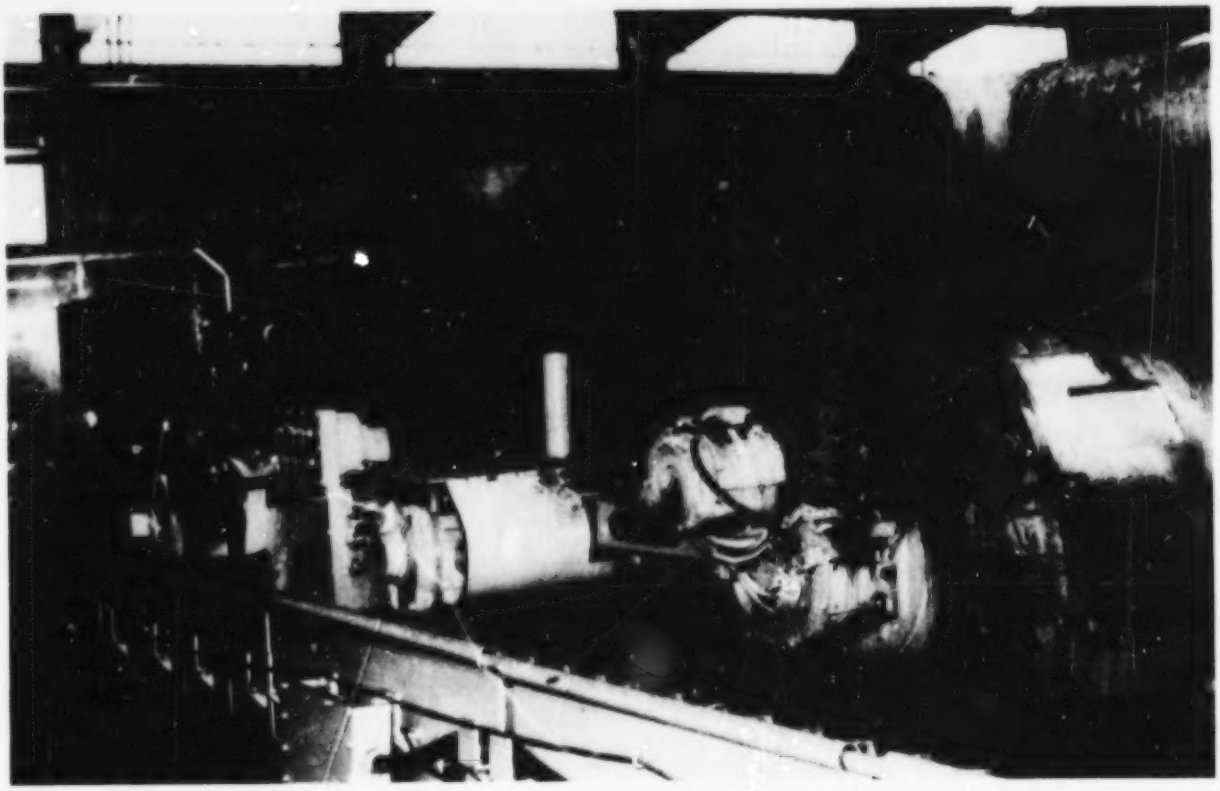

FIGURE 1. - Bureau of Mines longwall shearer.

(thickness of cut) varied from 25 to 29 in. The machine tram rate was maintained at approximately 5 ft/min. Drum rotation speed was 46 r/min (bit tip speed = 650 ft/min). Radial attack bits were used.

TEST PROCEDURE

During testing, three passes were made across the coalcrete block. Figure 2 diagrams these passes, showing the relative locations of each cut and the water pressures used. Dust data were analyzed for the sections of each pass indicated on figure 2. Each pass began with a sump cut, which allowed the face to be squared, prior to the first test cut.

For the first pass, the face was marked off into 6-ft-long segments. Each segment was cut while maintaining the water pressure shown in figure 2. Water pressure of 6,000 psi was used to cut 35 ft during the second pass; 35 ft of the third pass was cut using conventional-type spray nozzles with a water pressure of 190 psi. The final 15 ft of the third pass was cut without water sprays to provide information for comparison of dry cutting with conventional wet cutting and cutting with high-pressure sprays.

SPRAY SYSTEMS

There were 32 spray nozzles on the lead drum. With both high-pressure and conventional spray systems, water was supplied only to the lead drum. For the high-pressure and conventional-pressure tests, spray nozzles, having 0.024- and

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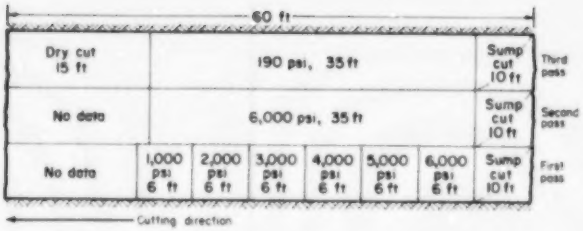

FIGURE 2. - Locations of test cuts and water pressures used.

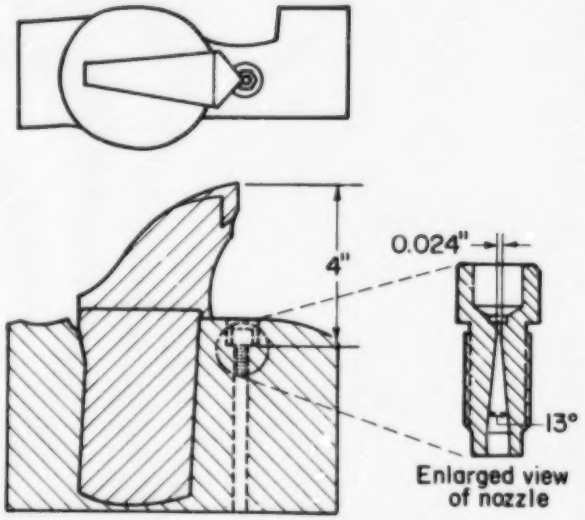

FIGURE 3. - Nozzle design and bit configuration.

0.071-in orifices, respectively, were located in front of each bit, approximately 4.0 in from the bit tip. The water-jet nozzles were made from stainless steel, 3/8-in-diam hexagonal socket head screws, which were machined down to an internal 13° Leach and Walker configuration. (See figure 3.) Brass nozzles of similar design (13° taper) were used for the conventional sprays. Each nozzle delivered a solid stream of water to a location 1 to 3 mm in front of the bit tip. Flow rates for nozzles operating at the pressures tested are given in table 1.

The water supply lines to the cutting drum were flushed frequently, and 10-μm filters were placed in line to reduce the possibility of nozzle blockage. The high-pressure water was supplied by a 150-hp triplex pump with a capacity of 50 gal/min at 6,000 psi.

DUST SAMPLING PROCEDURES

The cutting action of the Bureau shearer cutting in coalcrete was similar to that of a shearer cutting coal on an underground longwall face. However, the airflow pattern on an underground longwall face, which has a significant effect on the transport characteristics of airborne dust, could not be simulated during testing. Moreover, the amount of dust generated while cutting coalcrete versus coal would not be the same, due to physical differences in the two materials. No attempt was made, therefore, to relate dust levels measured during

TABLE 1. - Test conditions and sampling results

Pressure, psi	Flow rate, gal/min	Fluid horsepower[1]	Dust concentration, mg/m^3			Dust reduction, pct
			Exterior	Interior	Average	
High-pressure:[2]						
6,000.....	1.26	141.1	10.2	33.4	21.8	80.4
5,000.....	1.15	107.4	10.9	23.1	17.0	84.8
4,000.....	1.03	76.9	12.0	31.7	21.9	80.4
3,000.....	.90	50.4	11.6	34.8	23.2	79.2
2,000.....	.75	28.0	28.0	52.5	40.3	63.9
1,000.....	.54	10.1	92.4	121.2	106.8	4.2
Conventional:[3]						
190.....	.90	3.2	119.0	103.9	111.5	.0
Dry cutting.....	0	.0	102.0	223.0	162.5	-31.4

[1]Calculated for 32 sprays. [2]0.024-in orifice. [3]0.071-in orifice.

testing to those that would be measured during an actual underground mining operation.

Dorr-Oliver 10-mm nylon cyclones were used at each sampling location to eliminate all but airborne respirable dust. Two "exterior" cyclones were hung about 72 in from the cutting drum at approximately the same height as the top of the cut (fig. 4). The cyclone inlets were positioned away from the drum to reduce the chance of water droplets entering the cyclones. Two "interior" cyclones were placed inside a wooden dust sampling box on top of the shearer (fig. 4). The center of the box had a cross-sectional area of 1 ft^2. A centrifugal fan mounted on the sampling box pulled 80 ft^3/min of air into the sampling box through 2-1/2-in-diam PVC plastic tubing. The ends of the box were tapered to reduce sampling error due to airflow turbulence. The inlet for this sampling tubing was located approximately 24 in from the bottom of the lead drum (fig. 5). Therefore the exterior and interior cyclones sampled dust levels 72 and 24 in, respectively, from the lead drum.

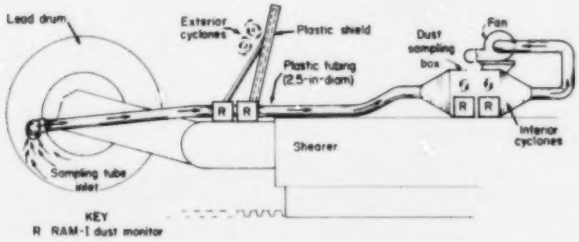

FIGURE 4. - Locations of sampling instruments on longwall shearer.

Interior and exterior cyclones were attached by 60-in lengths of Tygon plastic tubing to real-time aerosol dust monitors (GCA RAM 1's), which continuously monitored dust levels. The analog output from each monitor, which is proportional to the dust level, was recorded by a Soltec strip-chart recorder. For each test, the area under the recorded curve was measured using a compensating polar

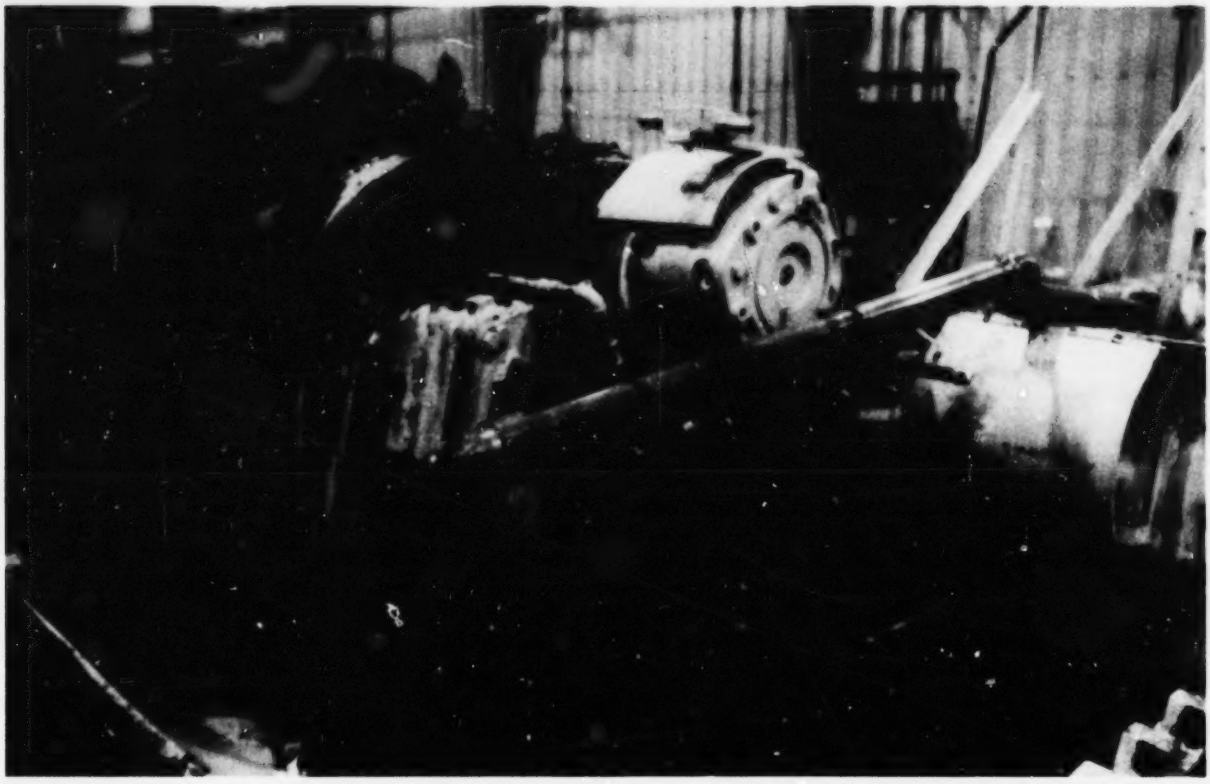

FIGURE 5. - Plastic tubing used for interior sampling location.

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planimeter. The length of the baseline under each curve was proportional to the duration of the test. Each area was divided by the length of the baseline to obtain an average dust concentration for the time of testing.

To reduce variation in sampling results, test conditions other than water pressure were reproduced for each test. Static pressure within the box was carefully monitored to determine if there were any constrictions in the airflow path or any changes in fan operation. For each test the same monitoring instruments (RAM 1's) were used at each location. Monitor performance was checked before each test by verifying that instrument airflow was correct and that the digital readout gave the calibrated value for the reference scatter.

DUST SAMPLING RESULTS

Table 1 shows the water pressure and flow rates used and the resulting dust levels at both sampling locations, as well as the average dust levels for both locations. The final column shows the dust reductions (versus conventional operation) for each water pressure and flow. At 3,000 psi water pressure the dust levels were 79.2 pct less than when using conventional sprays. The dust reduction at 3,000 psi was achieved with a water flow rate no greater than required for the conventional spray pressure of 190 psi. Raising the pressure further from 3,000 to 6,000 psi resulted in only small additional dust reductions.

DISCUSSION

The data in table 1 showed that the higher water pressures and flow rates required for water-jet-assisted cutting were effective in reducing levels of airborne dust. Increasing either water flow or pressure increased the amount of fluid energy that was supplied to the location being cut. During a prior study where water-jet-assisted cutting was used with a roadheader, energy supplied by the water jets enabled the roadheader to cut hard rock that could not be cut when operating dry (3). A part of the energy used reduced airbrorne dust.

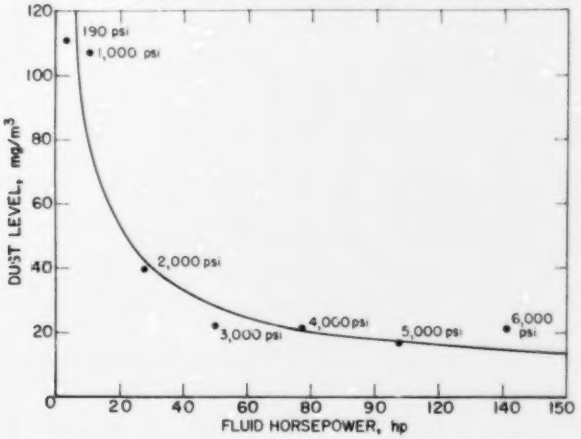

FIGURE 6. - Fluid horsepower versus dust level.

During these tests the tram rate and depth of cut were maintained relatively constant. Therefore the specific energy supplied by the sprays can be directly related to the fluid horsepower. The quantity, $P \times V/1714$, can be used to calculate fluid horsepower, with P being the pressure (psi) and V the volume (gal/min). In figure 6, fluid horsepower for the seven different water pressures tested has been plotted versus resulting dust levels. The data points have a correlation coefficient of 0.90 for the power curve ($y = ax^b$) shown. These data do not indicate whether increased flow or increased pressure is more important in causing changes in the dust level. There is probably a combined effect of pressure and flow, depending on the range of operating conditions.

Variations in dust concentrations, seen in table 1, can be attributed to various causes. When operating dry, dust levels at the two sampling locations varied primarily with respect to their distance from the dust source. Dust measured at the interior and exterior sampling locations was drawn from areas 24 and 72 in,

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respectively, from the cutting drum. Therefore, dust levels were higher at the interior sampling location.

When sprayed water is applied during a coal cutting operation, changes in airborne dust levels are primarily due to one or more of the following:

- Airborne capture of coal dust particles.
- Wetting of coal dust before it becomes airborne.
- Entrainment of dust particles caused by spray-induced airflow.

The contribution of each to dust suppression varies with the pressure and flow used.

At 190 psi the average dust concentration decreased mainly as a result of wetting the coal surface. The flow rate through each nozzle at 190 psi was 0.90 gal/min. However, underground and laboratory tests by the Bureau have shown that, in addition to wetting, water sprays can cause airflow turbulence that can have a significant effect on dust levels measured in the vicinity of a longwall shearer (4). If water spray nozzles mounted on the shearer body are not properly oriented, the resulting airflow can carry dust to the shearer operator's position. Although only drum-mounted sprays were used during these tests, in tests where the web width was less than the drum width, the sprays nearest the shearer body sprayed outside the coalcrete block. At 190 psi, these unshielded sprays created air turbulence that moved dust toward the exterior sampling location, resulting in slightly higher dust levels there than when operating dry.

Increasing the water pressure from 190 to 1,000 psi did not significantly change dust levels at either sampling location. Although the pressure increased, flow rate at 190 psi was greater than at 1,000 psi (0.90 vs 0.54), owing to the difference in nozzle orifice sizes. The total horsepower supplied by the sprays operating at 190 and 1,000 psi was 3.2 and 10.1, respectively. However, the added energy was not sufficient to significantly affect either wetting of the coal or airborne particle capture.

Dust levels were reduced 78 pct when the pressure was raised from 1,000 to 3,000 psi. The additional fluid horsepower supplied by the sprays operating at 3,000 psi resulted in improved dust control. Higher pressure resulted in increased flow, which improved wetting. Higher water pressures may have contributed to further dust reductions for the following reasons:

1. Water directed at the coal at high pressure penetrates a short distance into the coal surface (2), traveling along natural fracture planes in the coal and wetting the generated dust before it is exposed to the ambient airflow.

2. The dominant effect of the jets on the rock fracture process is to flush chips and rock debris from the region ahead of the bit (2). These particles are wetted by the jet before being removed from the face.

3. Material cut by the longwall drum "circulates" for a short time between uncut coalcrete and the drum vanes before the screw action of the vanes pulled it onto the panline. Water from the water jets penetrates the cut material more quickly and mixes more thoroughly as the material circulates. This results in a more uniformly moist mined material.

At pressures above 1,000 psi, airborne dust capture may have been a factor in reducing the airborne dust. Studies, such as those of Tomb (5), have shown that capture of airborne dust by water droplets increases with increased water flow and pressure. Minimum pressures are necessary before the effects of the capture become significant. Airborne dust capture is not effective unless the dust can be confined for a short time within a closed space. During cutting with the shearer, small water droplets within the kerf may strike and remove a portion of the dust that becomes airborne in this space. A British study (6) conducted on an operating longwall section suggests that the effectiveness of the high-pressure water may be due to better penetration of the material being cut or to atomization of the water stream into fast-moving fine droplets. It is not possible to determine from the data

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collected if the spray within the kerf affected dust levels more by improved wetting or by airborne capture.

There was only a small decrease in dust as the water pressure was raised from 3,000 to 6,000 psi. This was probably because the section of coalcrete cut at 3,000 psi was thoroughly wetted by the quantity of water applied at this pressure. The additional water supplied at the higher pressures could not be absorbed. Any additional dust reductions due to increased pressure were minimal.

CONCLUSIONS

The results of this study indicate that use of water-jet-assisted cutting can significantly reduce airborne dust generated by a longwall shearer. Water-jet-assisted cutting is characterized by increased water flow rate and water pressure, and by spray-induced airflow turbulence. Varying these operating conditions had the following effects on dust levels:

1. At 190 psi.--Although wetting of some dust occurred within the area being cut by the shearer drum, spray-induced airflow increased dust levels at the exterior sampling location.

2. From 190 to 1,000 psi.--Water flow decreased and fluid horsepower increased. The added fluid horsepower was not sufficient to offset the effect of reduced wetting.

3. From 1,000 to 3,000 psi.--Higher pressure resulted in more efficient wetting of cut and uncut material within the area cut by the shearer. Increased wetting occurred as flow rates increased. Less dust escaped from the area being cut, as a result of increased wetting and possibly of improved airborne capture. Therefore, airflow turbulence became less of a factor affecting dust levels. Dust levels were reduced by approximately 78 pct.

4. From 3,000 to 6,000 psi.--Water quantity at 3,000 psi provided maximum effective wetting for the amount of material being cut. Increased water pressure did not improve wetting significantly. For dust control, the benefits of increasing water pressure above 3,000 psi were small.

FUTURE RECOMMENDATIONS

The Bureau of Mines is involved in planning and conducting the following studies on the use of water-jet-assisted cutting for longwall mining:

1. A relationship existed between fluid horsepower (P×V) and dust level for all conditions when the sprays were operated. Further testing will be conducted to study the independent and interactive effects of water flow and pressure on dust levels.

2. Water-jet-assisted cutting hardware, now being developed, will be installed on a shearer that will be operated on an underground longwall face (7). Airborne respirable dust levels will be monitored during normal mining operations.

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